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APPLICATION

FOR

UNITED STATES OF AMERICA

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SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

Be it known that I,

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have invented certain improvements in

"METHOD FOR INCREASING THE BEARING CAPACITY OF FOUNDATION SOILS FOR ~~BUILDINGS~~" Built Structures

of which the following description in connection with the accompanying drawings is a specification, like reference characters on the drawings indicating like parts in the several figures.

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BACKGROUND OF THE INVENTION

The present invention relates to a method for increasing the bearing capacity of foundation soils for ~~buildings.~~ C1

Any building requires the foundation soil to have a sufficient bearing capacity to support it. Otherwise, the settling of the foundation soil leads to the failure of the overlying building, regardless of whether the settling occurs in the uppermost or in the deep layers.

Before erecting any building, the bearing capacity of the soil is therefore estimated according to the weight or load which the building will apply to the soil, even using, if necessary, appropriate soil research, such as for example geological and geotechnical research.

In order to ensure the stability of the structure, the optimum dimensions of the foundations and their rigidity are calculated and the depth of the foundations is also determined, adequately balancing their weight in relation to the bearing capacity of the soil and always maintaining a good safety margin. In case of error, the building may in fact fail.

Often, however, the bearing capacity of the foundation soil is not sufficient, since the soil is compressible, as in the case of filled-in land, non-consolidated land, land with decomposing organic layers, peaty land, swampy land, land with considerable variations in water content, flooded or washed-out land with voids or with non-uniform or insufficiently aggregated masses, land with interstitial voids, et cetera; or the building is very heavy and requires a greater bearing capacity than the actual bearing capacity of the foundation soil.

Various conventional systems ensure in any case the stability of the building. Generally, these systems tend to directly transfer the weight of the building to the deeper and adequately solid soil layers or to spread the load over a wide ground surface, such as for example the method consisting in driving piles or micropiles and the like into the foundation soil. This

method can be used both before and after construction.

Of course, the driving of piles and micropiles or the like after the construction of the building is extremely complicated and expensive.

Conventional methods also cope with any subsidence of the building after its construction, such as for example the method described in US patent 4,567,708, which entails the injection of an expandable substance beneath the building to fill the interstices which have formed and have caused the subsidence and in order to recover the subsidence of the building, or other lifting methods.

In the method disclosed in the above-cited patent, as well as in other lifting systems, however, the foundation soil is not treated; at the most, one acts on the surface layers of the soil, and therefore if the underlying soil has not settled enough, further subsequent subsidence of said building will occur over time.

A method for ground consolidation using, an expandable substance, in which the expansion time is controlled to be slow or very slow, is known from the document DE-A-33 32 256.

SUMMARY OF THE INVENTION

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A principal aim of the present invention is to solve the above problems by providing a method capable of ensuring the stability of C2 ~~buildings~~ by adequately treating the foundation soil in order to increase its bearing capacity. C3

Within the scope of this aim, an object of the present invention is to provide a method which does not require the use of cement, concrete, or metal structures driven into the ground, such as piles, micropiles, cement injections, very deep foundations, etcetera.

Another object of the present invention is to provide a method which is simple and easy to perform and can be adopted to increase the bearing capacity of foundation soils both before and after construction of the building.

This aim, these objects, and others which will become apparent hereinafter are achieved by a method for increasing the bearing capacity of foundation soils for built structures ~~buildings~~, according to the present invention, comprising the steps set forth in claims ~~claim 1~~.

BRIEF DESCRIPTION OF THE DRAWINGS

Further characteristics and advantages of the present invention will become apparent from the following detailed description of a preferred but not exclusive embodiment of the method according to the invention, illustrated only by way of non-limitative example in the accompanying drawings, wherein:

figure 1 is a schematic view of the injection of the expandable substance through holes formed in the soil;

figures 2 and 3 are views of the result of the expansion of the expandable substance when the substance is injected whilst the tube used for injection is gradually retracted upwards, respectively with pauses at intermediate depth levels or with a continuous motion;

figure 4 is a view of the result of the expansion of the injected substance in the case of sequential injections performed with different tubes, inserted in different holes, in points spaced from each other and at different depths;

figure 5 is a schematic view of an injection operation, according to the invention, with constant monitoring of the sinking recovery of a building foundation;

figures 6-8 are comparative diagrams of dynamic penetrometric tests carried out on a soil area treated according to the invention;

figure 9 is a sectional view of a soil area treated in accordance with the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The method according to the present invention substantially consists in forming in the soil a plurality of holes 1 which, if one must act on

existing buildings, may or may not pass through the foundation, at different depths and preferably with a distance between two contiguous holes 1 which can vary between 0.5 m and 3 m.

The holes 1 can have variable dimensions according to requirements and can be provided substantially vertically or at an angle with respect to the vertical.

The depth of the holes may also vary according to requirements, as will become apparent hereinafter.

Tubes 2 are then inserted or driven into the holes 1 and a substance 3 expanding as a consequence of a chemical reaction between the components, with a potential volume increase of at least five times the volume of the substance before expansion, is injected into the soil through said tubes. The expression "potential volume increase" relates to the volume increase of the substance as a consequence of an expansion occurring unhindered at atmospheric pressure.

High expansion coefficients of 20-25 times the initial volume or even higher such as 30-33 may be preferred.

The expandable substance is conveniently constituted by a mixture of expandable polyurethane foam, preferably a closed-cell polyurethane foam. This substance can be constituted, for example, by a two-part foam mixed inside a mixing unit 4 connected to the injection tubes 2. The first component can be a mixture of polyols comprising a polyether polyol and/or a polyester polyol, a catalyst, such as RESINOL AL 643 produced by the Dutch company Resina Chemie, and water. The water in the composition may be 3.44% by weight. The second component can be an isocyanate MDI, such as URESTYL 10 manufactured by the same company. The mixing of these two components produces an expandable polyurethane foam the density whereof, at the end of expansion, varies according to the resistance opposed by the soil adjacent to the injection region.

The mixture may expand up to about 33 times its initial volume and the reaction time is of about 3-6 seconds, as it appears from the technical specifications of the manufacturer.

It is of course also possible to use other expandable substances having similar properties without thereby abandoning the scope of the protection of the present invention.

According to requirements, the expandable substance can be injected through the holes 1 formed beforehand in the soil in a single injection step, as shown in figures 1, 2, and 3, starting from the bottom, whilst the injection tube is gradually retracted upwards, optionally with intermediate pauses, as shown in figure 2, so as to obtain different columns of hardened and expanded substance, or the substance can be injected, optionally by performing sequential injections at fixed and different depths in points which are three-dimensionally and uniformly spaced from each other so as to obtain regions of expanded and hardened substance within the foundation soil, as shown in particular in figure 4, according to requirements and according to the geological characteristics of the soil. In this last case, the tubes used for injection are left in the soil.

Once the substance 3 has been injected, since it has also penetrated in any voids and fractures of the soil thanks to its fluidity, expanding with great force and speed in all directions, it generates a force which compacts and compresses the soil all around, eliminating by compression or filling all voids and microvoids, even extremely small ones, expelling most of the water impregnating the soil, possibly agglomerating loose parts (granules and noncohesive parts) until a mass of soil is obtained which, throughout the treated layer, can no longer be compressed in relation to the weight that it has or will have to bear.

It should be noted that the expandable substance injected at different depths, in appropriately calculated points having a specific distance from each other, or along ascending lines, during expansion automatically

flows towards the more compressible points, which as such offer less resistance to the expandable substance. In this manner, the regions which most need treating are automatically treated more intensely, without leaving spaces with untreated regions.

The immediate nature of the expansion of the injected substance also allows to delimit the expansion region rather precisely, thus allowing to localize very well, in the intended points, the effect to be produced. The intense pressure applied by the injected substance to the surrounding soil is in fact due to the expansion caused by the chemical reaction and is not caused by hydraulic pressure. The expandable substance is injected through a hydraulic pressure which, however, only has the purpose of introducing the substance in the chosen points.

The immediate reaction of the injected substance, in terms of expansion and curing, prevents its migration to faraway areas, where a slow reacting substance may instead arrive. In fact, the slower the expansion reaction is the farther the substance arrives, to the detriment of the precise delimitation of the expansion effect and with consequent increase of the injection substance consumption.

Advantageously, since in the conditions of the invention the consolidation has a focused effect with low substance consumption, injection tubes may be used providing sufficient injection substance flow rates which have an inner diameter, for example of 10 mm, thus being easily insertable into and retractable from the soil. Tube diameters being smaller or larger by some millimeters are also usable. Anyway employing tubes with much larger diameters, of about 2 cm or more, difficult to drive into the soil, for obtaining high substance flow rates is not necessary.

To efficiently localize the effect of the consolidation, the injection may be carried out, with intermediate pauses. For example injection periods of 15 seconds may be alternated with pauses of 1-2

seconds or even longer. The durations of the active injection and respectively of the alternating pause periods are in fact selectable to be the more suitable considering factors such as the injection depth, the injection substance composition the length and the cross section of the injection tubes.

For obtaining a more rapid expansion reaction of the injected substance without having to switch to other compositions, where necessary, it is possible to raise by heating the temperature of the substance just before the injection operation.

As regards the hole depth, two different methods can be performed.

A first method consists in treating the entire thickness of the soil layers which are compressible or have a low bearing capacity, so as to perform consolidation up to the solid horizon of the layers having a sufficient bearing capacity, regardless of their depth. The solid horizon can be detected by means of geotechnical research conducted on the soil.

The second method instead consists in treating a layer of soil which, for reasons related to technical and/or economic convenience, does not reach down to the identified solid horizon, which might be located at an excessive depth, but is in any case thick enough to distribute the overlying weight over a wider surface. The layer of soil treated with the method according to the invention, by constituting a sufficiently compact, solid, and in any case light layer, can be effectively and broadly supported by the underlying layers of soil, even if those layers would not otherwise have a sufficient bearing capacity.

Until now, injection depth of up to 6 m have been successfully experimented, but with adapted tube cross-sections and accurately controlled substance injection flow rates, greater injection depths may be attained.

The expansion of the injected substance following the chemical reaction of its components is very fast and develops a very high

expansion force: up to 40 tons per square meter or even higher.

During injection, the level of the overlying building or of the surface soil can be constantly monitored by means of a laser level 5 or another system (see figure 5). When the apparatus 5 indicates that the building or the soil surface begins to rise, this generally means that the compaction of the soil, in three dimensions all around the injection point, has reached very high levels which are generally higher than the required minimum values.

Through the constant monitoring operation, the precise moment when the soil begins rising at a precise spot, due to the narrowly focused expansion force, and further the exact amount of the lifting are accurately detected and may be controlled in real time.

The mass of injected substance, by reacting chemically, in fact expands with great force in all directions, and when the apparatus detects even a small rise at the surface, this means that the expandable substance has encountered less resistance in expanding in the vertical direction with respect to all other directions and that therefore the soil lying below and around the injected substance withstands and "rejects" all the weight (which is dynamic and therefore multiplied) not only of the entire mass of soil (and of any building) which rests statically thereon, but also of all the surrounding mass displaced (by friction and cohesion) at a load diffusion angle which is usually calculated at around 30° and is simply inverted. The raised soil, too, undergoes compression.

By repeating this operation at different depth levels (spaced by approximately 1 meter from each other, but variably according to the kind of soil and to the bearing capacity to be obtained), at each level, a greater bearing capacity is obtained than the required one. By acting in this last manner and by performing continuous injections along rising columns, wherein tree-like shapes are formed with a very irregular configuration, with protrusions, bumps, and projections even of

considerable size produced by the different resistance of the soil to compaction and to the possible presence of interstices or fractures in the soil, in any case the entire mass and the treated layer of soil are compressed, packed and compacted; the water content decreases considerably; and the soil becomes a valid foundation soil adapted to stably support the building which lies above or is to be built.

The expandable substance can have a density varying indeed according to the resistance opposed by the surrounding soil to its expansion. In most cases, density can vary between 100 kg/m^3 and 300 kg/m^3. There may also be higher densities, since the density of the expanded substance is directly proportional to the resistance which it encounters to its expansion. The compression resistance of the expanded substance itself is a function of density.

A substance with a density of 100 kg/m^3 offers a resistance of approximately 14 kg/cm^2, whilst at a density of 300 kg/m^3 compression resistance is approximately 40 kg/cm^2. These values are far higher than those normally required for a foundation soil. In any case, where higher compression resistance values are required, even at different depths of the same soil, there is also a greater weight and therefore a higher resistance to expansion; accordingly, a denser and therefore stronger material forms automatically.

In any case, it is possible to momentarily add weight to a soil surface or to a building.

In practice, the injected and hardened expanded substance does not support the overlying building on its own, though helping to achieve this purpose; the weight of the building is effectively supported by the foundation soil treated with the method according to the invention.

In practice it has been observed that the method according to the invention fully achieves the intended aim and objects, since it allows, in a very simple, rapid, effective, and final manner, to increase the bearing

capacity of foundation soils until they fully comply with construction requirements.

Typically, in what seems to be a general trend in ground consolidation techniques, see for example the document DE-A-33 32 256, a very rapid expansion, with very high expansion coefficients, creating rapidly increasing pressures in the treated soil, is purposely avoided, since it was shown to provoke unwanted, mainly vertical, fissures in the treated mass ground.

In the conditions of the invention, however, it has surprisingly been noted that fissures occurring between soil masses, not only do not affect the soil compaction, but can in fact be advantageously exploited.

Technical tests and studies, carried out on built lots where the consolidation method of the invention has been used, have demonstrated that the expansion of the injected material occurs first in directions where the soil offers less resistance, but only for a limited extent. In the case of a built spot this happens, in the first place, laterally to the foundation and not in the vertical direction, where the weight of the building acts.

Only after the ground compaction degree is such as to provide a resistance to the lateral expansion forces well exceeding the weight force exerted by the building, a vertical force is obtained such as to raise the foundation and the building. In fact it is not only the weight of the building which has to be compensated for, but also other resistant forces, such as part of the weight of adjacent constructions, lateral friction forces and the flexural strength of the built structure itself.

While an immediate reaction of the injected material, in terms of expansion and solidification, may provoke indeed fissures between soil masses forced to move with respect to each other by rapidly increasing, strong forces, a certain quantity of the injected substance appears in fact to fill up the fissures so as to "weld" satisfactory the soil masses, at least in the area to be consolidated, which is immediately close to the

injection site and under the foundation of the built structure. For exemplification see figure 9, where a "welded" fissure may clearly be seen.

Penetrometric tests, the results whereof are shown in the diagrams of figures 6-8, have been carried out both under built spots treated with the consolidation method according to the invention, after a soil lifting has been sensed by the level apparatus , and laterally thereto, in close vicinity, at about 20 cm from the foundation.

From these diagrams showing comparatively the soil bearing capacity before consolidation (the not shadowed prisms) and after the consolidation (the shadowed prisms), clearly appears that the main consolidation occurs under the foundation, between 120 and about 300 cm of depth (figure 6), while at only 20 cm laterally from the foundation, the consolidation appears, at the same depths as before, significantly diminished (figure 7).

It is believed that this clearly shows the focused effect of the consolidation carried out according to the invention which practically provides a noteworthy reinforcement of mainly the soil under the foundations.

The diagram of figure 8, drawn in the condition where an amount of expandable substance has been injected which has not provoked any detectable lifting reaction of the soil under the building foundation, shows that in fact, laterally, at only 20 cm from the foundation, practically no effective soil compaction has occurred which would have allowed generation of the vertical force necessary to the lifting and thereby also limiting the area where fissures may occur.

The method according to the invention has successfully been applied to consolidate the ground and to compensate subsidences under heavily

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loaded foundations in airports, such as those of the runaways, in industrial and commercial constructions C4 as well as under very old, historic buildings and at archaeological sites.

Checkings of treated sites have been made recently, and have all given

satisfactory results. The inspections have been carried out in accordance with a procedure approved by the French Control Institute SOCOTEC consisting substantially in injecting, at a site selected by an inspector in a treated zone, at random, a small quantity of the injection substance (about 20% of the quantity initially injected). The result has been considered positive if the injection triggered at least a minimum lifting effect of the soil surface.

The method thus conceived is susceptible of numerous modifications and variations, all of which are within the scope of the inventive concept; all the details may furthermore be replaced with other technically equivalent elements.